APPENDIX A

A.1 EM39 Conductivity Probe Theory of Operation

The Geonics EM39 Conductivity Probe is a geophysical tool that measures the ground's electrical conductivity or resistivity using electrical induction techniques. Specifically it achieves this by inducing a constant amplitude, alternating electric current loop in the material surrounding the probe by generating a strong alternating magnetic field using a transmitting coil in a dipole configuration. The dipole configuration ensures that the electric currents generated (also called ground loops) are coaxial to the probe's axis, and focussed around the center of the probe. These current loops once they are established, in turn generate their own secondary magnetic fields, which are detected by a dipole receiver, a fixed separation from the transmitter. In the case of the EM39 this separation is 0.5 m. The strength of the secondary magnetic field and the magnitude of the electric current it induces in the receiving coil is proportional to the conductivity of the material surrounding the borehole and therefore can be calibrated to provide a measure of the surrounding materials conductivity.

The advantage of this design is that the induction probe can be designed to minimize the influence of the borehole fluids. In the case of the EM39 it is designed to be sensitive to electrical properties up to 1.0 m away from the borehole. This means that the conductivity of the borehole fluid will not influence the results. A disadvantage however is that the borehole casing has to be nonconductive otherwise it will electrically screen the probe and prevent it from inducing a ground loop in the surrounding material. This means that the probe is ineffective in steel cased holes, but works well in PVC, ABS or fiberglass cased holes.

A second consideration is that the conductivities measured are an apparent conductivity response and to determine the true response one must integrate the results. In practical terms this means that as one approaches an abrupt change in conductivity, what the probe detects is a gradual rise in conductivity values over a 0.5 m distance until the conductivity measured, peaks at the apparent conductivity value. Therefore for layers thicker than 0.5 m the conductivity measured is reflective of the materials' true conductivity and the relationship is quantifiable. For layers between 1.5 and 5 m the measured conductivity is within 20% of the true conductivity. For layers greater than 5 m thick the measured conductivity approximately equals the true conductivity. By modeling the response and matching the modeled conductivity curve with that measured, one can determine what the true resistivity profile is. It should be remembered however that the modeling solution is non-unique for layers thinner than 0.25 m. One may vary both the conductivity amplitude and the layer thickness to obtain the same curve response therefore the solutions are not

unique. It should also be noted that the conductivities measured are measured at a frequency of 39.3 kHz. The electrical properties of soils do vary with frequency due to attenuation effects, therefore there is not necessarily a direct correlation to values measured using handheld probes or soil boxes, as these readings are quite frequently taken at much lower frequencies, or even DC levels.

A.2 Natural Gamma Probe Theory of Operation

The natural gamma probe can be thought of as an electronic counter that is sensitive to gamma ray particles. Each time a gamma ray particle passes through the scintillation chamber detector the electronic counter is incremented by one. Therefore the higher the counts/second the more gamma ray particles have been detected. In natural soils the source of this gamma radiation are three naturally occurring radioactive decay sequences. They are:

1. Potassium40
2. Thorium
3. Uranium-Radium

In most soils the radioactive Potassium40 sequence is by far the most common. Radioactive Potassium comprises 0.01% of all Potassium, but where Potassium is present, that percentage holds. The Uranium and Thorium sequences occur in sedimentary materials or may be present when specific radioactive minerals such as Monazite are present. In addition, because of their absorption and ion exchange capacity, clay minerals have the ability to absorb the heavy radioactive isotopes released by these two sequences as well as retaining their own intrinsic radioactive sources. As a result clay minerals have much higher natural gamma levels than other soils. Therefore typically speaking, when one is dealing with overburden material, higher gamma readings indicate a higher proportion of fine-grained clayey particles, while lower readings are more indicative of sands and gravels. One should note however that if concentrations of particular elements are present gamma particles may be preferentially absorbed yielding lower than usual readings. Lead would one such material.

There is always a degree of scatter in the gamma counts measured due to the statistical nature of the measurement. Having said that, the vertical discrimination of the gamma probe is quite good due to the physically small size of the sensor, therefore it is quite capable of detecting small beds in the order of several centimetres in size.